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A blind channel shortening for multiuser, multicarrier CDMA system over multipath fading channel

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Abstract

In this paper we derive the Multicarrier Equalization by Restoration of Redundancy (MERRY) algorithm: A blind, adaptive channel shortening algorithm for updating a Time-domain Equalizer (TEQ) in a system employing MultiCarrier Code Division Multiple Access (MC-CDMA) modulation. We show that the MERRY algorithm applied to the MC-CDMA system converges considerably more rapidly than in the Orthogonal Frequency Division Multiplexing (OFDM) system [1]. Simulations results are provided to demonstrate the performance of the algorithm.

Keywords*: blind time-domain equalizer, guard time, MMSE equalizer, multi-carrier CDMA, multi-carrier modulation, multipath fading channels, orthogonal frequency division multiplexing OFDM*

1. Introduction

Single-carrier systems have more stringent equalization requirements than multi-carrier systems like orthogonal frequency division multiplexing. The impact of the channel will be flat fading on each carrier, when the channel is shorter than the cyclic prefix (CP). Since the request for higher bit rates is increasing, several works developed novel techniques to spread spectral efficiency. As long as the Cyclic Prefix (CP) is longer than the channel delay spread, the Multi-Carrier Modulation (MCM) method [2, 3] can easily resolve channel dispersion. The model solution is to exercise a channel-shortening equalizer (TEQ). Several techniques to TEQ scheme are non-adaptive, have high difficulty, and need a channel estimate. While there are approaches for blind channel extraction for multicarrier systems, there is only one "blind" adaptive method that directly equalizes the channel. However, [4] carry out complete equalization rather than channel shortening. An efficient means of implementing the modulation is to use an Inverse Fast Fourier Transform (IFFT). After transmission and reception, an FFT can be used for the demodulation [3, 4]. In order for the sub-channels to be independent, the convolution of the signal and the channel must be a circular convolution. It is actually a linear convolution, so it is made to appear circular by adding a CP to the start of each data block [5-7], which is obtained by prepending the last samples of each block to the beginning of the block. If the channel is shorter than the CP, then the output of each sub-channel is equal to the input times a scalar gain factor. If the CP is not as long as the channel delay spread, then Inter-Channel Interference (ICI) and Inter-Symbol Interference (ISI) will be present, and a channel-shortening (time-domain) equalizer, or TEQ, is needed. The TEQ is chosen such that the convolution of the channel and TEQ has almost all of its energy in a time window no longer than the CP length. TEQ design (for a *static* environment) has been well explored, notably in [8-12].

2. Blind Adaptive Channel Schortener

In this part, the description of the CP, consider the baseband model of a typical multicarrier modulation system, as shown in Figure 1. Each block of bits is divided up into N bins, and each bin is viewed as being modulated by a different carrier.

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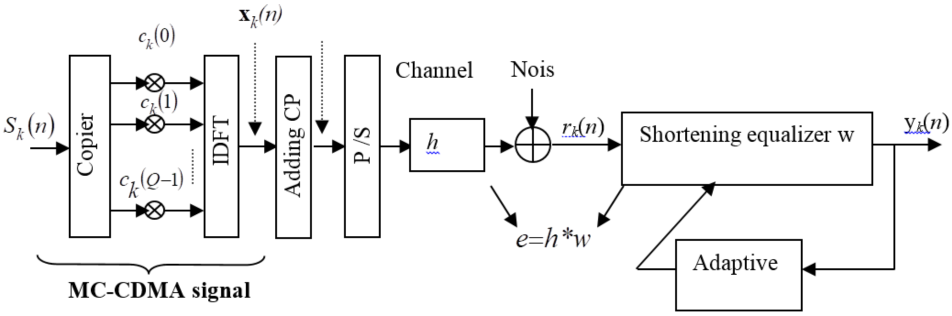

Figure 1. Channel shortening with a blind equalization for MC-CDMA system

This section derives the basic MERRY algorithm, and discusses the various generalization and performance-enhancing extensions. For the moment consider a MC-CDMA system in Figure 1. Once CP has been added, the transmitted data obeys the relation [8, 10].

$$x(M.n+i)=x(M.n+i+N) \quad i\in\{1,2,\cdots,v\} \tag{1}$$

Where $M=N+v$ the total symbol duration, and n is the symbol index. To simplify the notation, henceforth we assume *n=0 (without loss of generality).* The received data **r** is obtained from **x** by

$$\mathbf{r}_k(i)=\sum_{l=0}^{L_h-1} h(l)\,.\,\underline{\mathbf{x}}_k(i-l)+n(i) \tag{2}$$

and the equalizer data ***y*** is similarly obtained from **r** by

$$y_k(i) \;=\; \sum_{j=0}^{T-1} w(j)\,.\,\mathbf{r}_k(i-j) \tag{3}$$

The combined channel is denoted by *e* = *h* * *w*, and *T* is the length of the equalizer **w.** Here $\boldsymbol{x}_k(n)$ with dimensions $Q \times 1$ is defined as

$$\mathbf{x}_k(n)=\begin{bmatrix}x_k(n,0) & x_k(n,1) & \cdots & x_k(n,Q-1)\end{bmatrix}^T \tag{4}$$

and is composed of samples during the n^{th} MC-CDMA symbol transmitted by the k^{th} user. The CP can convert the time-domain linear convolution of the FIR channel to a cyclic convolution; the ISI is eliminated with the aid of CP. The transmitted sequence with CP is

$$\underline{\mathbf{x}}_k(n)=\begin{bmatrix}x_k(n,Q-v)\\ \vdots \\ x_k(n,Q-2)\\ x_k(n,Q-1)\\ x_k(n,0)\\ x_k(n,1)\\ \vdots\\ x_k(n,Q-v)\\ \vdots\\ x_k(n,Q-2)\\ x_k(n,Q-1)\end{bmatrix} \tag{5}$$

for clarity, the time-domain Channel Impulse Response (CIR) vector for the k^{th} user is described as

$$\mathbf{h}_k = \left[h_k(0)\ h_k(1)\ \cdots\ h_k(L_{ch})\right]^T \tag{6}$$

3. Merry Algorithm

The channel destroys the relationship in (1), because the ICI & ISI that affect the CP are different from the ICI & ISI that affect the last samples in the symbol. The astute reader will also note that we have shortened the channel to v taps, yet a multicarrier system only requires shortening to $v+1$ taps. However, when v is large (32 in Asymmetric Digital Subscriber Loops (ADSL)), shortening the channel by an extra tap should have a minimal effect on the performance in general, if the channel order $L_{ch} \leq v$ (has been shortened), then the last sample in the CP should match the last sample in the symbol. One cost function that reflects this is [11]:

$$J_{merry}(\delta) = E\left[\ \left|y(\nu+\delta) - y(\nu+N+\delta)\right|^2\right] \qquad \delta \in \{0,\ldots,M-1\} \tag{7}$$

where δ is the symbol synchronization parameter, which represents the desired delay of the effective channel (channel +TEQ). The proposed (MERRY) algorithm [1, 9], performs a stochastic gradient descent of (7), with a constraint (such that w=1) to avoid the trivial solution w=0. This algorithm is as follows: [13-18]

MERRY:

Given δ, for symbol n=0, 1…,

$$\tilde{\mathbf{r}}(n) = \mathbf{r}(n+\nu+\delta) - \mathbf{r}(n+\nu+N+\delta)$$

$$y(n) = \mathbf{w}^T(n)\tilde{\mathbf{r}}(n)$$

$$\hat{\mathbf{w}}(n+1) = \mathbf{w}(n) - \mu y(n)\tilde{\mathbf{r}}^*(n)$$

$$\mathbf{w}(n+1) = \frac{\hat{\mathbf{w}}(n+1)}{\left\|\mathbf{w}(n+1)\right\|}$$

where

$$\mathbf{r}(n) = \left[r(n),\ r(n-1),\ \cdots,\ r(n-L_w)\right]^T \tag{8}$$

(*) denotes complex conjugation, and μ is the TEQ adaptation step size, taken equal to: 0.75 [19, 20].

4. Simulation Results

In this section, we consider a standard DSL test channel, using Carrier Serving Area Loop 1(CSA1) [12]. It's consists of 512 samples, the BPSK modulation is used with a (AWGN) signal to noise ratio equal to 40 dB. For case of ADSL the FFT size is 512, and the CP is *v=32.* The number of coefficients of TEQ equalizer equals 16. The plot is computed by the running of 5000 symbols, and 50000 iterations. We consider the block diagram system of the Figure 1 where ***h*** is an ADSL channel as shown in Figure 2. Numerical results are obtained by the adaptation of the Matlab code available at [12].

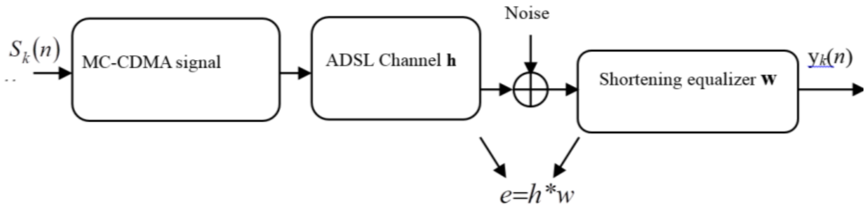

Figure 2. Diagram of blocks for Channel shortening with a blind equalization for MC-CDMA system

4.1. Comparative Results
4.1.1. The ISI

The ISI *vs.* number of iterations is presented in Figure 3, the curve is decreasing, it attains the -4.407 at 100^{the} iteration, the jaggedness is until has 3700 iterations and it stabilize after 50000 iterations. The curve converges rapidly comparing to that obtained with OFDM system in this case (dashed line) [12] the curve attaining -4.397 at 400^{the} iteration. The ISI function is defined as [12, 13]:

$$ISI = \frac{\sum_k |e_k|^2 - max\left(|e_k|^2\right)}{max\left(|e_k|^2\right)} \tag{9}$$

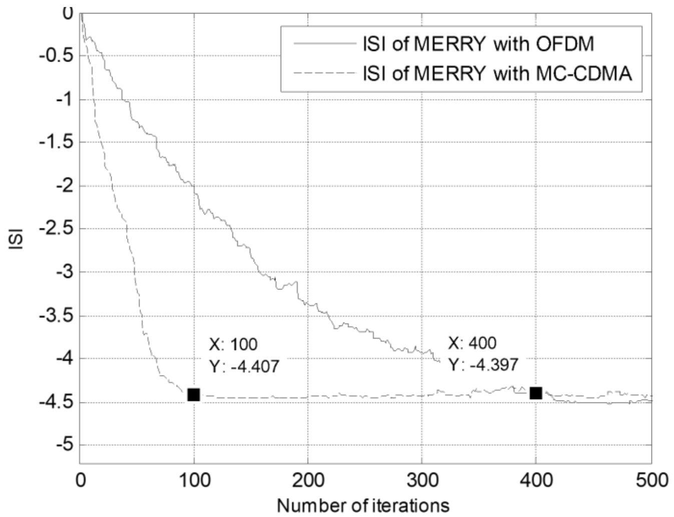

Figure 3. The performance of MC-CDMA system with TEQ equalizer in term of ISI

4.1.2. The Bit Rate

The DSL performance metric is the achievable bit rate for a fixed probability of error [8, 10-14]:

$$R = \sum_i lg_2\left(1 + \frac{SINR_i}{\Gamma}\right) \tag{10}$$

where $SINR_i$, is the signal to interference and noise ratio in frequency bin *i.* Γ is the SNR gap [21-25]

$$\Gamma = \gamma_{md} + \gamma_m - \gamma_c \tag{11}$$

γ_{md} is the modulation gap=9.8 dB, γ_c is the coding gain$\approx$4.2 dB and γ_m is the margin=6 dB.

Figure 4 shows the bit rate *vs* SNR, the bit rate was computed by running for 5000 symbols. For all these SNR values the MERRY applied to MC-CDMA approaches the Maximum Shortening SNR (MSSNR) solution [9], and the both presents a minimal bit rate for SNR=50 dB compared to OFDM [11].

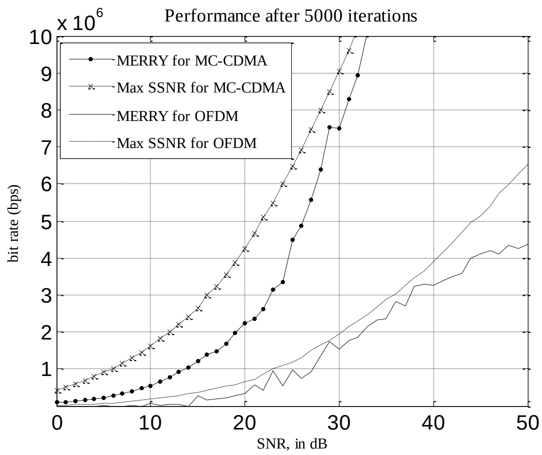

Figure 4. Achievable bit rate vs SNR for MERRY on CSALoop1 for MC-CDMA system

5. Conclusion

The MERRY algorithms carry out blind adaptive channel shortening. It is less difficulty and mainly convergent. A method was proposed which calculated the time-domain filter coefficients for MC-CDMA systems .And the similar technique was suggested to evaluate the coefficient of a TEQ with arbitrary length. The performance of the TEQ is estimated and the MC-CDMA system is assumed in the simulation. It can be seen that the TEQ achieves excellent performance for MC-CDMA system.

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